

# Operations Concept Definition – European Style

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*Abstract*— In a time when there is increased pressure to reduce mission cost, the European Space Operations Centre (ESOC) of the European Space Agency (ESA) is trying to maintain a focus on mission success by trying to streamline operations without increasing the overall mission risks. An increased investment is made in the definition phase of a mission, with the aim to reduce cost through proper planning, preparation and utilization of emerging technologies.

The European Space Community has a complex structure, with players from all countries competing for contracts in both the Space Segment and Ground Segment/Operations (GS/Ops) fields. As a consequence, politics play an important role in defining the overall programmatic structure of any European mission. This adds a certain degree of complexity, but also promotes competition and distribution of competence, two factors that hold long-term advantages, enabling Europe to remain one of the major players in the global space community.

The challenges presented by the changing economical and political climate have resulted in a change in how ESOC handles/coordinates GS/Ops concept definition activities.

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## 1. INTRODUCTION

The European Space Operations Centre (ESOC) has a long history of successful mission operations, dating back to before the European Space Agency (ESA) was created. Since the creation of ESA the organization has grown to

comprise sites all over Europe (see Figure 1), and directly or indirectly provides work for tens of thousands of people in space-related activities, either as ESA staff members or by carrying out services for ESA through agreements with industry.



Figure 1 - The Major ESA Sites in Europe

The primary ESA sites are:

- HQ – ESA Headquarters (Paris, France)
- ESTEC – European Space Research and Technology Centre (Noordwijk, Netherlands)
- ESOC – European Space Operations Centre (Darmstadt, Germany)
- ESRIN – European Space Research Institute (Frascati, Italy)
- EAC – European Astronaut Centre (Cologne, Germany)
- Ground Station Network with Ground Stations located all over the World
- Liason sites all over the World (USA, Russia, etc.)

At the time ESA was created there were few (if any) national space operation centres, so all of the GS/Ops expertise was gathered into one pan-European centre. The

purpose of this centre was to support all European space missions, and it has done so successfully since. A list of some of the missions supported by ESOC is presented in Table 1. The complete list comprises more than 80 satellites. Only a few of the milestone missions where ESOC had full operations are included here. For the complete list of missions see [1].

A large number of missions are currently in preparation for launch (Integral, Rosetta, Mars Express, to name a few), and several of these will have been launched by March 2003.

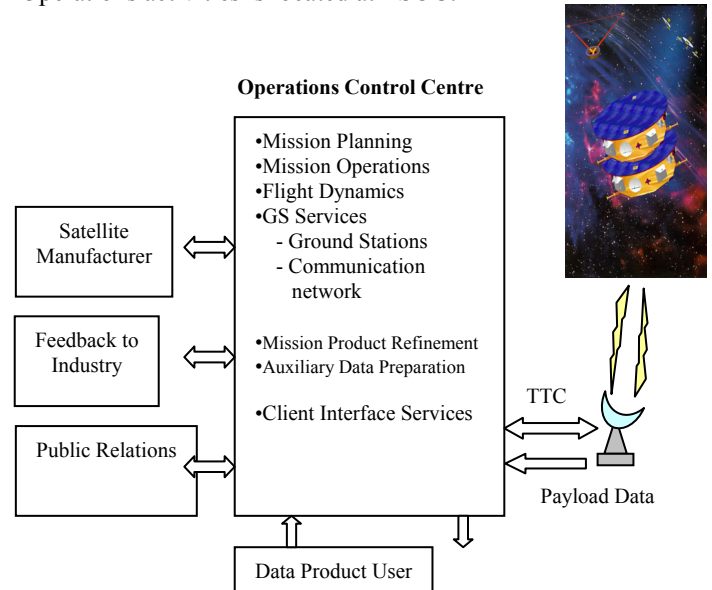
The missions supported by ESOC range from small and simple to large and highly complex. This variety has enabled ESOC to build up considerable expertise in all areas of satellite operations. All aspects of spacecraft ground segment/operations are covered by ESOC activities, as the breakdown of a typical ESOC Ground Segment in Figure 2 shows.

**Table 1- Past Missions Supported by ESOC**

Mission	Launch	Comment
ESRO-2	May-68	First ESOC Mission
HEOS-A1	Dec-68	First ESOC HEO mission
ANS	Aug-74	First ESOC-operated non-ESA mission
Meteosat-1	Nov-77	Weather Satellite
OTS-2	May-78	First ESOC Telecom mission
GIOTTO	Jul-85	First ESOC Deep Space Mission (Haley's comet)
Hipparcos	Aug-89	Star Catalogue mission
Ulysses	Oct-90	Polar orbit around the Sun
Eureca	Jul-92	Launched and retrieved by the Space Shuttle
ERS-1/2	91/95	Earth Observation
HUYGENS	Oct-97	Flying on Cassini – will land on Saturn's moon Titan in 2004
XMM-Newton	Dec-99	X-Ray Observatory
CLUSTER-II	Jul-00 Aug-00	Cluster of 4 satellites in Constellation
ENVISAT	Feb-02	Europe's largest ever satellite Earth Observation

As space activities have become more commonplace, national agencies within Europe have started building up their own operations centres to support their dedicated national missions and potentially serve as sites for larger European missions. In addition, industry has started offering GS/Ops as part of their turnkey-type mission proposals. This shift of focus from a single European space operations centre to a number of centres for member states has resulted in a marketplace with several sites being in a position to

offer ground segment and operations facilities and services. The question that arises is: How should this be coordinated and who should do it? An initiative called the Network of Centres has been started that will (amongst others) serve as the overall coordination facility for Ground Segment and Operations of European missions. The ESA coordination facility for Network of Centres Ground Segment and Operations activities is located at ESOC.



**Figure 2 - - A Typical ESOC Ground Segment**

With this evolution of the political environment in the European space domain in the last decade, it has become clear that the way missions are planned has had to change. With the increased GS/Ops resources spread throughout Europe (operations centers and ground stations), ESOC will coordinate ESA mission operations activities through the Network of Centres initiative. Each time a new mission is selected for evaluation, ESOC can contact the Network of Centres participants to see which facilities would be available for a mission, and once an appropriate Ground Segment configuration can be identified, the process of cooperation can begin.

In the field of GS/Ops it is vital that processes and technologies evolve in line with improvements in science and technology in other domains. Achieving this in a field where "failure is not an option" presents a great challenge. A unit in ESOC has been established that is dedicated to keeping an eye on new technological developments and studying ways of applying these technologies for future missions.

## 2. THE ESA MISSION LIFECYCLE

Space programme development phases are very similar in all the major space agencies of the world (ref. [2]). The ESA spacecraft mission lifecycle is well defined and very linear. The phases are alphabetized as follows:

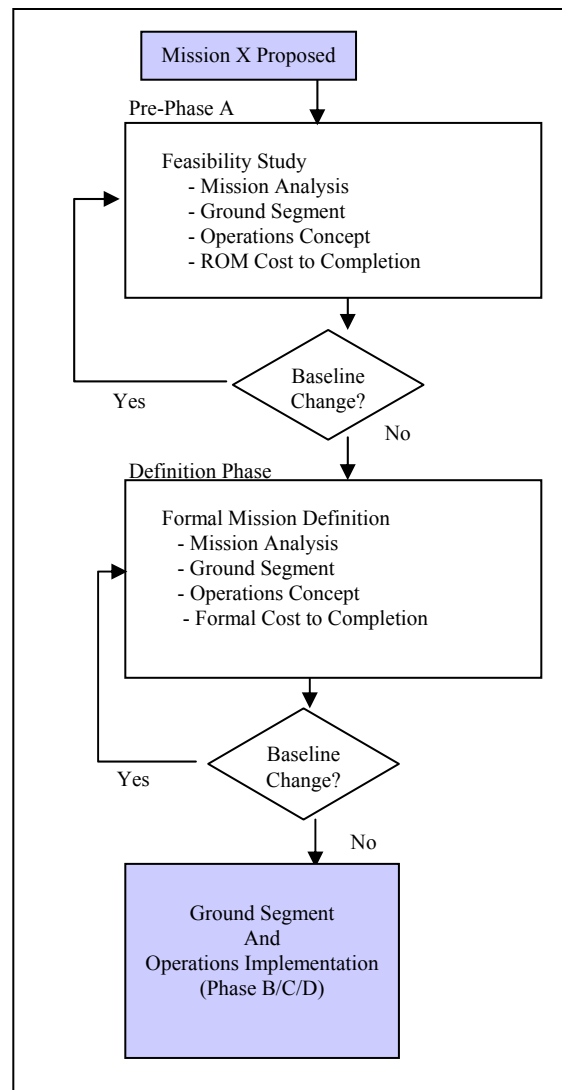
- Phase A – Feasibility Study**  
 A mission is proposed to ESA, and all areas of the mission (space segment and ground segment) are studied. An early mission design is developed and the Cost-to-Completion (CTC) for the whole mission is calculated. This activity is carried out by ESA and Industry. In parallel, the GS/Ops team (typically ESOC) carries out the GS/Ops definition, in cooperation with their industrial counterparts on the Space Segment side.
- Phase B – Preliminary Definition**  
 At this point a mission is approved with a budgetary ceiling (based on the Phase A CTC). The company/companies selected to implement the space segment studies the preliminary Phase A Space Segment design and proposes its complete Space Segment design. At ESOC, the Ground Segment and Operations teams are created, and early specification/implementation of the Ground Segment begins.
- Phase C – Detailed Definition**  
 The specifications for the individual subsystems of the mission are made on both the space segment and ground segment side. This will be presented at two Critical Design Reviews (CDRs), one for the Space Segment and one for GS/Ops. If approved, the mission will be implemented as specified.
- Phase D – Production/Ground Qualification Testing**  
 This is when the actual implementation phase of the space segment of a mission is developed. The end of this phase is defined by a very specific milestone: launch of the spacecraft.
- Phase E – Utilisation**  
 The Spacecraft has been launched and is in use (or in preparation for use)
- Phase F – Disposal**  
 The spacecraft is put in a safe (graveyard) orbit or disposed of.

### 3. THE “NEW” WAY OF GETTING READY

In practice, the phases are not as well defined as they were in the past, in particular in the early phases. One now normally talks about “Phase A”, “Phase B/C/D” and “Phase E”. This is how the contracts with Industry are normally split. This section will focus on Phases A and B, and highlight the “new” way of doing GS/Ops concept definition in ESA.

One of the primary changes to have taken place over the last few years in the area of GS/Ops concept definition is the creation of a Unit in ESOC dedicated to this purpose; The Future Studies Unit. In the past, experts “between missions” were asked to provide inputs to GS/Ops preparation. This system worked, and created the foundations for all ESA missions operated by ESOC. to the full satisfaction of the Spacecraft users. But – where such a best-effort scenario

fails today is that the (overloaded) experts will tend to take a previous mission and tailor it for the new mission, because they simply have other activities that are more pressing (such as launch preparation or spacecraft contingencies). Of course, in most cases this will produce a GS/Ops concept that will satisfy the mission success criteria. What it doesn’t leave room for is evolution or improvement of the technologies or methods involved with GS/Ops activities. Now that there is a dedicated team responsible for all ESA GS/Ops concept definition, the process is more streamlined, allowing for greater focus on an overall European GS/Ops strategy rather than isolated focus on individual missions.



**Figure 3 - The Flow From Mission Proposal to GS/Ops Implementation**

The overall process from a mission being proposed to it being approved and the start of implementation has been expanded compared to the traditional ESA model described in Section 2. A typical GS/Ops concept definition cycle now has the structure illustrated in Figure 3.

### Pre-Phase A

During this phase a mission feasibility study is carried out. This typically has to be executed very fast, because a go/no-go decision is often based on the output of this phase. This activity used to be carried out by a small team of people from the space segment. The team would send requests out to all parties involved with a mission (including a GS/Ops contact) with a brief mission overview, asking for inputs. Once these inputs were received those requested would try to consolidate all the information from their field and send it back to the contributors for review. This is a process, that, due to lack of direct communication between parties, would require several iterations before a coherent result was achieved. Due to advances in conferencing technology it has now been possible to improve this system. In ESA a new facility, the **Concurrent Design Facility (CDF)** has been created. This is a facility that enables representatives from all aspects of a spacecraft mission, space and ground segment, to get together and discuss a mission in real-time. Each participant has his/her own console containing all mission information, and as things change during discussion/calculation this information can be updated centrally once all parties agree.



**Figure 4** - The Concurrent Design Facility at ESTEC

This process typically involves two ½-day sessions per week for 3-4 weeks. The primary CDF is located in ESTEC, and in the past the ESOC Mission Analysis and GS/Ops representatives had to travel there to take part in the sessions. Now a similar (albeit smaller) CDF has been set up in ESOC for Mission analysis and GS/Ops activities, allowing full videoconferencing with the ESTEC CDF. This has several benefits: reduced travel costs, direct access to tools and documentation available only at ESOC, and the possibility to invite other GS/Ops participants on short notice. The ESOC system also has capabilities for hooking up to other European sites, such as national operations centers, ground stations etc.

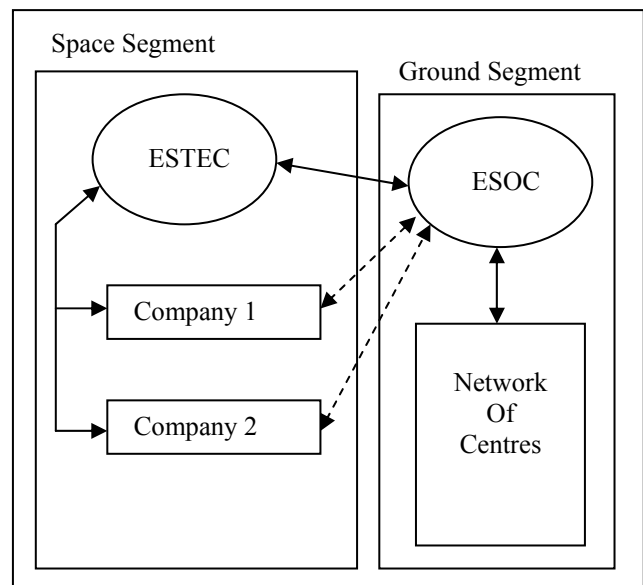
Once the mission concept is defined the process of establishing a Rough Order of Magnitude (ROM) Cost-to-

Completion (CTC) is initiated. On the GS/Ops side this is based on a Study Assumptions Note (SAN). This note contains all the information required for managers to assess the cost of the different subsystems of the Ground Segment.

### The Definition Phase

This phase covers what used to be call Phase A. However, many missions continue carrying out traditional Phase A activities after phase A is formally complete. They often term these activities “Phase B0” “early Phase B” etc. The term “Definition Phase” is therefore a more complete term covering all activities before a mission is fully defined.

The Definition Phase can typically **not** be carried out in the same manner as Pre-Phase A, as at this stage considerable effort has to be invested to get the details of each part of GS/Ops correct. All parameters (such as link budgets, orbit selection/maneuvers, etc.) have to be very accurately calculated and documentation that serves as input to the implementation of GS/Ops has to be generated. The formal cost of the GS/Ops is also calculated during this phase. The definition phase activities are carried out in close cooperation with the Space Segment Team in ESTEC, and with the Industry teams carrying out definition phase contracts. There are typically two independent teams carrying out definition phase studies for the ESA Space Segment. This is partly done to avoid being bound to any specific company before the mission is fully designed, and partly to allow for some choice of design and implementation strategy before the final decisions are made.



**Figure 5** - Definition Phase Organisation

As can be seen from Figure 5, ESOC serves as the overall coordinator for all GS/Ops related definition phase activities for ESA missions, working together with the Network of Centres Office to evaluate which sites would be suited to participate in the mission being defined.

For the definition phase of every mission, a team is created with representatives from all aspects of GS/Ops:

- Ground Stations and Communications
- Mission Control Systems/Simulations
- Mission Analysis
- Mission Operations
- Flight Dynamics/Orbit Determination

A representative of the Future Studies Unit acts as the Study Manager for this team and has the overall responsibility for the Definition Phase activities and outputs.

The outputs of the Definition Phase are a set of documents that should be sufficient for the GS/Ops team to carry out the implementation and operations of the mission. These documents are:

- **Mission Assumptions Document (MAD)**  
This document contains the overall mission definition and describes the Ground Segment for the mission and the overall Operations Concept.
- **Consolidated Report on Mission Analysis (CREMA)**  
This document contains all the analysis carried out by the Mission Analysis team in the areas of launcher selection, transfer orbits, orbit selection, maneuvers required, etc.
- **Space to Ground Interface Control Document (SGICD)**  
This document defines the interface between the spacecraft and ground. In fact, the document is split into several sections. One is generated by the GS/Ops team (RF and Communications) and the other (Spacecraft TM/TC) by the Space Segment team during the implementation phase (Phase B/C/D)
- **Operations Interface Requirements Document (OIRD)**  
This document contains the requirements the Ground Segment has on the Space Segment.
- **Cost to Completion (CTC)**  
Primarily based on the Mission Assumptions Document, this document contains the overall cost of the GS/Ops of the mission. This serves as input to the overall cost of the complete mission.
- **Other Technical Documentation**  
No two missions are identical. For each mission new investigations have to be made, and the results of these investigations have to be documented. This is particularly relevant in the operation of science missions such as deep-space or exotic high-precision formation flying missions.

Once all the definition phase documents have been produced and handed over to the Mission Project Manager, the mission enters the implementation phase. A Ground

Segment Manager (GSM) is appointed and he/she sets up the team that starts implementing the GS/Ops concept defined in the Mission Assumptions Document.

One of the challenges of carrying out the definition phase of any mission is that the experts needed to properly define the GS/Ops of a mission are normally overloaded, and have to prioritize missions that are in more critical phases (pre-launch, contingency situations, etc.). Considering that definition phases in the past were considered an extra activity which people were asked to do “if they had time”, the experts need to be educated that the early phases of a mission are very important and should be given as much priority as missions at later stages of their lifecycles. Many of the missions currently in the pre-phase A or definition phase launch in the 2010-2015 timeframe. By highlighting the activities that are ongoing for future missions to the staff at ESOC and making it clear that concepts being defined now will have to be implemented by them in the not-so-distant future seems to get the point across. There is a special unit dedicated to GS/Ops concept definition that is in a position to be able to carry out specialist tasks if the specialists are not available. If the specialists do not have time to support the GS/Ops definition of a given mission, the Future Studies Unit is in a position to take over such specialized activities, provided support for questions and answers is available. Since this policy has been introduced, it has become easier to get the required results in the required timeframe. The ideal would naturally be that all the experts had time to support definition phase activities when required, but this is not the case. The Future Studies Unit was created partially with this in mind. That being said, no decisions are made without the relevant experts being given a chance to provide their inputs.

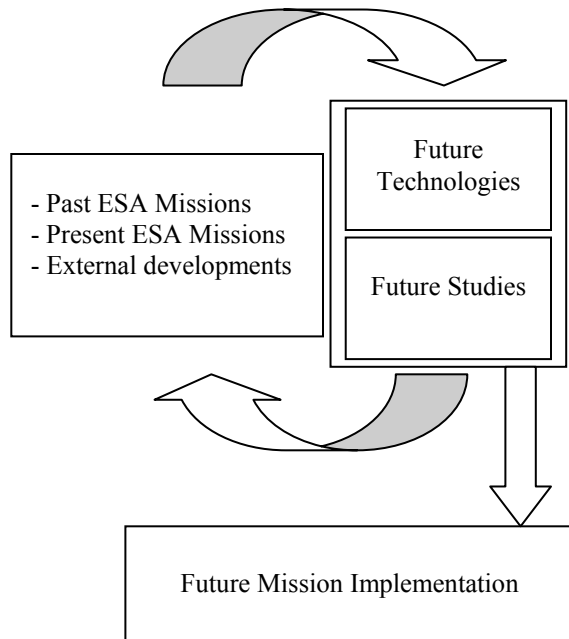
#### *Innovation vs. the “If it ain’t broke” syndrome*

When defining the GS/Ops of a mission it is vital that experience from previous and ongoing missions be fed back into the loop. In addition, impulses from the outside have to be fed into the system at the pre-phase A/definition phase level in order to be effective. In other words, a mix of tried and tested vs. new and progressive is required. Such a mix is not easy to get right.

For something as failure intolerant as the space industry the natural approach is conservatism. “If it ain’t broke, don’t fix it”. However, having a fully functioning sword when other people have moved on to guns won’t get you far. This applies not only to new technologies (see Section 5), but also to new ways of thinking. The American motto in the space industry “faster, better, cheaper” (“FBC”) may not have produced the results one had hoped, but it did open the space industry’s eyes to the fact that the world has moved on since the Apollo days, and new ways of implementing space missions must be investigated. The European space industry has embraced the “FBC” philosophy only partially, with certain missions being classified as “risk is accepted”



missions. When such a classification is made, one area that often gets asked to cut costs is Ground Segment and Operations. As the European center of competence in the area of GS/Ops activities we have a responsibility to identify new methods for cost-effective ground segment and operations implementation, either through in-house studies or by keeping abreast of what is going on outside the Agency, in other space agencies and in universities/Research and Development (R&D) centers, as illustrated in Figure 6.



**Figure 6** - Learning from all sides.

#### 4. NEW TECHNOLOGIES

*Why do we need new technologies? For what?*

Innovative GS/Ops approaches for future missions may require a key contribution from instrumental new technologies, suitable for the scope. Operations processes, including tasks such as scheduling, planning, monitoring, diagnostics, control and resource management make use of a mixture of hardware, software, procedures and trained operations engineers. The question is; can we live with the current approach (and solutions) or do we need something better? In what areas?

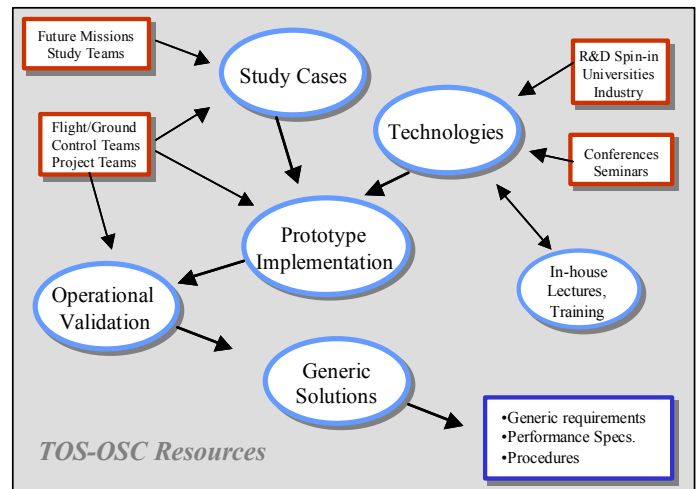
Pre-phase A activities and early design refinement already provide a first attempt in identifying improvement requirements on the current mission control infrastructure approach, either for efficiency (i.e. cost reduction) objectives, or due to new functional requirements, not yet implemented in the current infrastructure.

To answer these questions a new Control Technology unit has been recently founded at ESOC to identify, investigate

and bread-board new technology driven solutions in support of future mission operations.

#### *Current technology exploitation approach*

A fundamental lesson learned from past experience has been the need to have the “users” of the new technology-driven solution not only as recipients but also as prime actors in the design, development and implementation of new prototyped solutions. In other words, most of the R&D must be case-driven and the output not just a pure demonstrator, but something to be run, used and evaluated on the field. In addition, it is clear that an appropriate methodology is required to sustain and manage the research activity coherently, within the budgetary constraints.



**Figure 7** – Control Technology Unit working approach

As a result, the Control Technologies Unit is now working following the approach summarized in Figure 7.

New potential R&D study cases are constantly identified and updated from the pre-phase A and definition phases of future missions. Improvement requirements coming from currently flying missions are also taken into consideration. In parallel, technology investigations are carried out to identify and select suitable technology configurations for use in the implementation of the cases. At present this list includes fuzzy logic, genetic programming, artificial neural network, time series analysis, Kalman filtering, data mining, data fusion and knowledge engineering.

The case selection is driven by different criteria such as urgency, re-usability and (functional and economic) potential benefits. The outputs of the R&D studies generate operational prototypes that undergo operational validation.

This period is actually among the most crucial ones, where the final users – the space and ground operations engineers – make use of and evaluate the benefits and limitations of the implemented tool and of its associated technology.

Quite often, to better evaluate the impact of new tools and technologies it is necessary to have real flight data cases, not available for mission going to fly in 8-10 years time. A suitable on-going mission in the routine operations phase is therefore identified, with similar orbital and mission objective characteristics to the target mission. The implementation and the operational validation is therefore done using the real data of the flying mission, giving greater confidence in the usefulness of the new technology/tool.

With this approach we are prepared in advance to identify a technology-driven implementation solution for a future mission, lowering the uncertainty risk and familiarizing the operational personnel with the new proposed technology.

The selected Rapid Application Development (RAD) approach followed in the technology prototyping activity has been inspired by the Dynamic System Development Method (DSDM) [3], a de-facto industrial RAD approach currently used in the Information and Communication Technology domain.

Time driven prioritized delivery and active involvement of the user community throughout the development lifecycle are among the advantages of this approach.

#### *Results and improvements*

The approach has already produced valuable positive results. An example is the ENVISAT gyroscopes monitoring, diagnostic and reporting tool [4], powered by fuzzy logic. Another is the Reaction Wheels Bias Maneuver Optimization Tool for XMM and INTEGRAL astronomic observatories [5], making use of genetic algorithms. Both tools are now under operational validation. The feedback from the operations personnel so far is positive and quantifiable. There is improved functionality capable of anticipating on-board gyro failure alarms and automating the performance reporting. In the second case an average fuel savings of 35% has been achieved in the de-saturation of the reaction wheels with respect to the current standard approach.

Focused localized improvements of effectiveness and efficiency of the mission control process are not the only benefits we could expect from technology-driven investigations. Future plans might well include a focused re-engineering of specific mission control processes, for getting cost reduction and/or improved performance at an acceptable risk. Operator training & re-training, mission database population and mission knowledge sharing might become topics for consideration in the near future.

## 5. CONCLUSIONS

With the creation of the Future Studies Unit and the Control Technologies Unit, ESOC has given increased priority to improving the processes governing defining the GS/Ops of future missions. It is now easier to introduce new technologies into these missions at an early stage of their development. The importance of spending more time on planning for the future has been widely accepted in ESOC, even though this may sometimes mean a deviation from the tried and tested.

Given the economical and political situation in Europe it is important for ESOC to maintain its role as a coordinator of Europe's multi-national space missions in the areas of Ground Segment and Operations. To ensure this, it is vital that proper attention is given to this coordination during GS/Ops preparation. The Network of Centres Office has been created at ESOC to facilitate such cooperation.

As the ESA Operation Centre, ESOC has to remain at the forefront of spacecraft operations, not only by demonstrating that it can continuously successfully operate all types of missions, but also by being innovative and efficient in doing so. By having one team dedicated to looking after future missions and one dedicated to evaluating and defining future technologies, ESA/ESOC has ensured that progress and evolution can go hand-in-hand with successful implementation of the GS/Ops of future European missions.

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